Dr. Merriman No. 13

With the Author's best compliments

AN

EXPERIMENTAL ENQUIRY

INTO

THE MODES OF WARMING AND VENTILATING APARTMENTS,

IN REFERENCE TO THE HEALTH OF THEIR INMATES.

By ANDREW URE, M.D. F.R.S.

MEMBER OF THE GEOLOGICAL AND ASTRONOMICAL SOCIETIES OF LONDON;
MEM. ACAD. N. S. PHILAD.; CORRESP. MEMBER OF THE PHARM. SOC. NORTH GERMANY,
OF THE SOCIE'TE' INDUSTRIELLE DE MULHAUSEN, ETC. ETC.

Read before the Royal Society, 16th June, 1836.

The subjects of warming and ventilating apartments, in reference to the comfort and health of their inmates, have lately excited a great deal of attention. The commissioners delegated by government to enquire into the circumstances of factory labour adverted in their reports to some of the expedients employed for ventilating certain cotton mills; and, more recently, a select committee of the House of Commons has considered and reported upon the best mode of ventilating and warming the new Houses of Parliament. In an extensive tour which I made, during the two preceding seasons, through England, France, and Belgium, to investigate the applications of chemical and mechanical science to manufactures, I paid particular attention to these subjects, so interesting to science, as well as humanity; and I have had my mind professionally turned to them by the Directors of the Customs Fund of Life Assurance, on account of the very general state of indisposition and disease prevailing among those of their officers (nearly 100 in number) engaged on duty in the Long Room of the Custom House, London. I now respectfully submit the result of my observations and experiments on these points of public interest to the Royal Society.

The symptoms of disorder experienced by the several gentlemen (about twenty in number), whom I examined out of a great many who were indisposed, were of a very uniform character. The following is the result of my researches: —

A sense of tension or fulness in the head, with occasional flushings of the countenance, throbbing of the temples, and vertigo, followed, not unfrequently, with a confusion of ideas, ner's apartment in the Custom-house. It consists of a series of inverted, hollow, flattened pyramids of cast iron, with an oblong base, rather small in their dimensions, to do their work sufficiently in cold weather when moderately heated. The inside of the pyramids is exposed to the flames of coke furnaces, which heat them frequently to incandescence, while currents of cold air are directed to their exterior surfaces by numerous sheet-iron channels. The incandescence of these pyramids, or bells, as they are vulgarly called, was proved by pieces of paper taking fire when I laid them on the summits. Again, since air becomes electrical when it is rapidly blown upon the surfaces of certain bodies, it occurred to me that the air which escapes into the Examiner's Room might be in this predicament. It certainly excites the sensation of a cobweb playing round the head, which is well known to all who are familiar with electrical machines. To determine this point, I presented a condensing gold-leaf electrometer to the said current of hot air, and obtained faint divergence, with negative electricity. The electricity must be impaired in its tension, however, in consequence of the air escaping through an iron grating, and striking against the flat iron valves, both of which will tend to restore the electric equilibrium. The air blast, moreover, by being diffused round the glass of the condenser apparatus, would somewhat mask the appearances. Were it worth while, an apparatus might be readily constructed for determining this point, without any such sources of fallacy. The influence of an atmosphere charged with electricity in exciting headach and confusion of thought in many persons, is universally known.

The fetid burned odour of the stove air, and its excessive avidity for moisture, are of themselves, however, sufficient causes of the general indisposition produced among the gentlemen who are permanently exposed to it in the discharge of their public duties.

From there being nearly a vacuum, as to aqueous vapour, in the said air, while there is nearly a plenum in the external atmosphere round about the Custom-house, the vicissitudes of feeling in those who have occasion to go out and in frequently must be highly detrimental to health. The permanent action of an artificially desiccated air on the animal economy may be stated as follows: —

The living body is continually emitting a transpirable matter, the quantity of which, in a grown up man, will depend partly on the activity of the cutaneous exhalents, and partly on the relative dryness or moisture of the circumambient medium. Its average amount, in common circumstances, has been estimated at 20 ounces in twenty-four hours.

When plunged in a very dry air, the insensible perspiration will be increased; and, as it is a true evaporation or gasefaction, it will generate cold proportionably to its amount. Those parts of the body which are most insulated in the air, and furthest from the heart, such as the extremities, will feel this refrigerating influence most powerfully. Hence the coldness of the hands and feet, so generally felt by the inmates of the apartment, though its temperature be at or above 60°. The brain, being screened by the skull from this evaporating influence, will remain relatively hot, and will get surcharged, besides, with the fluids which are repelled from the extremities by the condensation, or contraction, of the blood-vessels caused by cold. Hence the affections of the head, such as tension, and its dangerous consequences. If sensible perspiration happen, from debility, to break forth from a system previously relaxed, and plunged into dry air, so attractive of vapour, it will be of the kind called a cold clammy sweat on the sides and back, as experienced by many inmates of the Long Room.

Such, in my humble apprehension, is a rationale of the phenomena observed at the Custom-house. Similar effects have resulted from hot-air stoves of a similar kind in many other situations.

After the most mature physical and medical investigation, I am of opinion that the circumstances above specified cannot act permanently upon human beings, without impairing their constitutions, and reducing the value of their lives. The Directors of the Customs Fund are therefore justified in their apprehensions, "that the mode of heating the Long Room is injurious to the health of persons employed therein, and that it must unduly shorten the duration of life."

It is evident, moreover, that the public service must suffer serious inconvenience in consequence of so many revenue officers, of great experience in business, being constantly exposed to the influence of a cause under which the most perspicacious intellect may become confused, and the most vigorous frame may be frequently disqualified for the discharge of a daily recurring duty. In fact, the absences among the officers of the Long Room in consequence of indisposition must be detrimental to the service, and may, for the most part, be traced to the malaria of the stoves.

For the purpose of producing a comfortable temperature in the air of the rooms occupied by individuals of a sedentary calling, like the in-door officers of His Majesty's Customs, cast-iron pipes, circulating steam a few degrees above the 212th degree of Fahrenheit's scale, should be distributed along the floor, close to the line of desks within which the officers sit. A corresponding range of small orifices should be made in the lower part of the desk partitions, for permitting the free ingress of the warm air around their limbs; and a series of sliding plates should be attached, for regulating these orifices, so as to enable each individual to suit the supply of warmth to his peculiar feelings and constitution. Self-acting register valves should, at the same time, be fixed aloft in the Long Room, which would regulate the discharge of foul air, and maintain a wholesome ventilation in the air below.

Nothing can be more preposterous, in an economical and scientific point of view, than the mode of introducing the hot air into the Long Room, through two wide vertical tunnels in the line of its centre, whence it rises rapidly to the lofty roof, and can communicate warmth to the inmates, seated near the floor, only by reverberating downwards in a polluted state of mixture, with many cutaneous and pulmonary exhalations. Whereas the great principle of ventilation is, never to present the same portion of air twice over to the human lungs, but to supply them at each fresh inspiration with pure aerial particles, in a genial thermometric and hygrometric condition. Such air should be poured in, rightly prepared, from innumerable orifices in or near the floor, and pass up over the living frames, never to be thrown back upon them, but to be discharged through an equivalent number of orifices in the ceiling, too small to permit a counter current of cold air downwards. By such ceaseless circulation, comfort and health would be permanently secured, at probably one fourth part of the expenditure of fuel now consumed in corrupting the aerial element, and in placing many valuable lives in jeopardy.

In the recent report of the Parliamentary Committee, it is truly surprising that not a syllable is said about the methods of warming and ventilating apartments employed in the factories, although they afford unquestionably the best models for imitation, being the results of innumerable experiments made on a magnificent scale, with all the lights of science, and all the resources of our ablest civil engineers.

The warming is effected by horizontal ranges of cast-iron steam-pipes, properly supported or suspended, so as to give free play to their expansion and contraction from alternations of temperature, as well as to secure the equable distribution of low-pressure steam, and the ready efflux of the water of condensation. There cannot be a single doubt of this system being the only one which can, with safety, certainty, and economy, be used in preparing in one or more antechambers a body of genial air, to be thereafter diffused through the Houses of Parliament and their subordinate committee rooms. The only point which can admit of discussion is, the mode of renewing the atmosphere, or what is commonly called ventilation. In this respect, also, the engineers of the metropolis will find themselves outstripped by those of Manchester, and some other factory districts.

Various schemes were resorted to, at the suggestion of several ingenious projectors, for ventilating the old House of Lords. Two, at least, of the plans consisted in the erection of a stove furnace in a chamber over that house, and in drawing the air for the supply of that furnace from the apartment below, so as to suck out the foul and hot atmosphere accumulated under its ceiling. The ventilating power of such an apparatus would be proportional to the quantity of fuel consumed, and the rapidity of its combustion; both being dependent, of course, upon the height of the chimney. It is well known that the contrivance was quite inefficient to refresh the air when it was most wanted; namely, when the house was crowded.

The quantity of air discharged in a given time by chimney draughts does not seem to have been hitherto made the subject of very accurate experiments. Whenever a certain volume of air is heated from the freezing to the boiling point of water, it expands into one volume and three eighths; and it therefore tends to rise up with a force equal to the difference between the weight of the volume of the cold air, whose space it now occupies, and its own weight; that is, in the present case, the difference between one and three eighths, and one; or 11 and 8.

Let us suppose a chimney, 50 yards high, to be supplied constantly at the bottom with air heated to 212°, while the external atmosphere is 32° Fahr. The tunnel, being full of the hot air, its ascensional force will be obviously the difference between the weights of two columns of air, each 50 yards high, the one at the boiling, and the other at the freezing, temperature of water: the force will, likewise, be the same as that acting in a siphon filled with air, and having one of its arms longer than the other, by the difference between the bulk of the cold and the hot air. This columnar difference of weight is the sole cause of the movement; and it is well known, both by theory and experiment, that the velocity of discharge through this columnar difference, which, in the present case, is $18\frac{3}{4}$ yards, would be equal to the velocity which a solid body would acquire in falling freely from that height. But a body falling from the height of $56\frac{1}{4}$ ft. would pass through 60 ft. per second, which is the velocity of efflux sought. A small deduction ought to be made from this number, on account of the increased density of the burned air in chimneys, in consequence of the replacement of a portion of its oxygen by carbonic acid.

The density of burned air, as it issues from chimney-tops, compared with that of atmospheric air of the same temperature, may be reckoned as $104\frac{1}{2}$ to 100. In practice, it will be found convenient to make the calculations as if the air were chemically the same, and to multiply the velocity found by 0·97; which would reduce the above 60 ft. to 58·2 ft.

Such are the results of theory; but they vary considerably from practice, in consequence of the varying lengths and forms of the chimney, which change the velocity of the aerial currents by friction, refrigeration, &c. In high chimneys of wrought iron, like those of steam-boats, the refrigeration is considerable, and causes a diminution of velocity far greater than what occurs in a factory stalk of well-built brickwork. In comparing the numbers resulting from the trials made on chimneys of different materials and of different forms, it has been concluded that the obstruction to the draught of the air, or the deduction to be made from the theoretical velocity of efflux, is directly proportional to the length of the chimneys and to the square of the velocity, and inversely to their diameter. With an ordinary wrought-iron pipe, of from 4 in. to 5 in. diameter, attached to an ordinary stove burning good charcoal, the difference is prodigious between the velocity calculated by the above theoretical rule, and that observed by means of a stop-watch, and the ascent of a puff of smoke from a little tow, dipped in oil of turpentine, thrust quickly into the fire. The chimney being 45 ft. high, the temperature of the atmosphere 68° Fahr., the velocity per second was, —

Trials.	By Theory.	By Experiment.	Mean Temperature of Chimney.
1	26·4 feet	5 feet.	190° Fahr.
2	29·4	5·76	214°
3	34·5	6·3	270°

To obtain congruity between calculation and experiment, several circumstances must be introduced into our formulæ. In the first place, the theoretical velocity must be multiplied by a factor, which is different according as the chimney is made of bricks, pottery, sheet iron, or cast iron. This factor must be multiplied by the square root of the diameter of the chimney (supposed to be round), divided by its length, increased by four times its diameter. Thus, for pottery, its expression is $2{\cdot}06\sqrt{\frac{D}{L+D}}$; D being the diameter, and L the length, of the chimney.

A pottery chimney, 33 ft. high, and 7 in. in diameter, when the excess of its mean temperature above that of the atmosphere was 205° Fahr., had a pressure of hot air equal to 11·7 ft., and a velocity of 7·2 ft. per second. By calculating from the last formula, the same number very nearly is obtained. In none of the experiments did the velocity exceed 12 ft. per second, when the difference of temperature was more than 410° Fahr.

Every different form of chimney would require a special set of experiments to be made for determining the proper factor to be used.

This troublesome operation may be saved by the judicious application of a delicate differential barometer, such as that invented by Dr. Wollaston; though this instrument does not seem to have been applied by its very ingenious author in measuring the draughts or ventilating powers of furnaces.

If into one leg of this differential siphon, water be put, and fine spermaceti oil into the other, we shall have two liquids, which are to each other in density as the numbers 8 and 7. If proof spirit be employed instead of water, we shall then have the relation of very nearly 20 to 19. I have made experiments on furnace draughts with the instrument in each of these states, and find the water and oil siphon to be sufficiently sensible: for the weaker draughts of common fireplaces the spirits and oil will be preferable barometric fluids.

To the lateral projecting tube of the instrument, as described by Dr. Wollaston, I found it necessary to attach a stopcock, in order to cut off the action of the chimney, while placing the siphon, to allow of its being fixed in a proper state of adjustment, with its junction line of the oil and water at the zero of the scale. Since a slight deviation of the legs of the siphon from the perpendicular changes very considerably the line of the level, this adjustment should be made secure by fixing the horizontal pipe tightly into a round hole bored into the chimney-stalk, or drilled through the furnace door. On gently turning the stopcock, the difference of atmospherical pressure, corresponding to the chimney draught, will be immediately indicated by the ascent of the junction-line of the liquids in the siphon. This modification of apparatus permits the experiment to be readily rectified by again shutting off the draught, when the air will slowly re-enter the siphon; because the projecting tube of the barometer is thrust into the stopcock, but not hermetically joined; whereby its junction line is allowed to return to the zero of the scale in the course of a few seconds.

Out of many experiments made with this instrument, I shall content myself with describing a few, very carefully performed at the breweries of Messrs. Truman, Hanbury, and Buxton, and of Sir H. Meux, Bart., and at the machine factory of Messrs. Braithwaite; in the latter of which I was assisted by Captain Ericsson. In the first trials at the breweries, the end of the stopcock attached to the differential barometer was lapped round with hemp, and made fast into the circular peep-hole of the furnace door of a wort copper, communicating with two upright parallel chimneys, each 18 in. square, and 50 ft. high. The fire was burning with fully its average intensity at the time. The adjustment of the level being perfect, the stopcock orifice was opened, and the junction level of the oil and water rose steadily, and stood at 1¼ in., corresponding to $\frac{1{\cdot}25}{8} = 0{\cdot}156$ of 1 in.

of water, or a column of air 10·7 ft. high. This difference of pressure indicates a velocity of 26 ft. per second. In a second set of experiments, the extremity of the stopcock was inserted into a hole bored through the chimney-stalk of the boiler of a Boulton and Watt steam-engine of twenty horses' power. The area of this chimney was exactly 18 in. square at the level of the bored hole, and its summit rose 50 ft. above it. The fire-grate was about 10 ft. below that level. On opening the stopcock, the junction line rose $2\frac{1}{4}$ in. This experiment was verified by repetition on different days, with fires burning at their average intensity, and consuming fully 12 lb. of the best coals hourly for each horse's power, or nearly one ton and a third in twelve hours. If we divide the number $2\frac{1}{4}$ by 8, the quotient 0·28 will represent the fractional part of 1 in. of water, supported in the siphon by the unbalanced pressure of the atmosphere in the said chimney; which corresponds to $19\frac{1}{4}$ ft. of air, and indicates a velocity in the chimney current of 35 ft per second. The consumption of fuel was much more considerable in the immense grate under the wort copper, than it was under the steam-engine boiler.

In my experiments at Messrs. Braithwaite's factory, the maximum displacement of the junction line was 1 in., when the differential oil and water barometer was placed in direct communication with a chimney 15 in. square, belonging to a steam boiler, and when the fire was made to burn so fiercely, that, on opening the safety-valve of the boiler, the excess of steam beyond the consumption of the engine rushed out with such violence as to fill the whole premises. The pressure of one eighth of an inch of water denotes a velocity of draught of 23·4 ft. per second.

The differential barometer was next attached to the suction-chamber of a ventilator fan, used for drawing the air through the fireplace, in the ingenious steam boiler of Messrs. Braithwaite and Ericsson's patent construction. The result was remarkable. Here the draught was so great, that it became necessary to remove the oil, and to employ merely a water siphon. When the speed of the circumference of the revolving vanes was 120 ft. per second, the suction was sufficient to support steadily 2 in. of water. This aqueous column, however, indicates a velocity of only 94 ft. per second, instead of 120. The pressure of air equivalent to this velocity is 224 vertical feet; equal to a column of water $3\frac{1}{4}$ in. high. But we must consider that the true velocity of the impelling points of the vanes is only seven eighths of the velocity of their tips, or 105 ft. per second. If this circumstance be not taken into account, we should be led to infer that, in an eccentric ventilator of the best centrifugal form, so much air escapes, by inertia, between the vanes and the sides of the box in which they revolve, as to cause a loss of nearly one fourth of velocity in the issuing current. Every principle of physics forbids us to suppose, as some engineers have hastily done, that the siphon pressure indicates only three fourths of the effects of the current upon the atmospheric equilibrium. On this point we shall presently offer some other illustrations.

When the wings of the fan were made to revolve with a velocity of 180 ft. per second, by connecting its rigger band with a larger driving pulley, the difference of water level in the two legs of the siphon amounted to only 3 in.; an unbalanced pressure, which indicates a velocity of efflux in the air of only 115 ft. per second, and a defalcation of effect, therefore, tantamount to 30 per cent, which is evidently due to the greater effect of inertia at that degree of speed; the effective velocity of the vanes being taken, as formerly, at seven eighths of that of their extremities.

In a third set of experiments, when the extremities of the vanes revolved with a velocity of 80 ft. per second, the water stood 1 in. higher in the one leg of the siphon than in the other. This difference of level indicates a velocity of 66 ft. per second. Here the loss of velocity, from the inertia and the eddies of the lateral portions of air, is only 6 per cent upon the effective velocity.

The following table exhibits the velocities of the air corresponding to different altitudes of the differential water barometer: —

12 inches of water correspond to a velocity of	231 feet per second.
6	163
3	115
2	94
$1\frac{1}{2}$	81
1	66
$\frac{1}{2}$	47
$\frac{1}{4}$	33
$\frac{1}{7}$	25
$\frac{1}{8}$ = 1 in. of the water-oil siphon	23·4

It has been ascertained, that a power equivalent to one horse, in a steam-engine, will drive, at the rate of 80 ft. per second, a fan the effective surfaces of whose vanes, and whose inhaling conduits, have each an area of 18 in. square, equal to that of the steam-boiler chimney mentioned above. The velocity of air in the chimney, produced by a consumption of fuel equivalent to the power of twenty horses, was no more than 35 ft. per second; while that of the fan, as impelled by the power of one horse, was 66 ft. per second. Hence it appears, that the economy of ventilation by the fan is to that by the chimney draught as 66 is to $\frac{35}{20}$, or as 38 to 1. It is obvious, therefore, that, with one bushel or ton of coals consumed in working a steam-impelled eccentric fan, we can obtain as great a degree of ventilation, or we can displace as great a body of air, as we could with 38 bushels or tons of coals consumed in creating a chimney draught. Economy, cleanliness, and compactness of construction are not, however, the sole advantages which the mechanical system of ventilation possesses over the physical. It is infallible, even under such vicissitudes of wind and weather as would essentially obstruct any chimney-draught ventilation, because it discharges the air with a momentum quite eddy-proof, and it may be increased, diminished, or stopped altogether, in the twinkling of an eye, by the mere shifting of a band from one pulley to another, as is practised upon all spinning-machines. No state of atmosphere without, no humidity of air within, can resist its power. It will expel the air of a crowded room, loaded with the vesicular vapours of perspiration, with equal certainty as the driest and most expansive.

The preference due to the mechanical system may be made popularly plain, by considering how little power could be obtained by applying a chimney current to impel machinery, through the agency of the best-going smoke-jack, or any other analogous construction. It is clear that the consumption of fuel, applied through the medium of steam, which produces the power of twenty horses in the above steam-engine, would, by the impulsion of an ascending current of air upon any mechanism, barely do the work of half a horse.

In an analogous experiment made at the brewery of Messrs. Truman, Hanbury, and Buxton, the differential barometer being placed in communication, as above described, with the chimney-stalk of the steam-engine boiler, suffered a change of level in the junction line of oil and water of 2¼ in., equivalent, as before, to 0·28 of 1 in. of water. The chimney had an area of 16 in. by 18 in. at the point where the lateral tube of the barometer was inserted, and it rose 50 ft. above that point.

About 12 lb. of coal were consumed hourly for each horse power, and steam corresponding to the power of fifteen horses, at least, was generated in each boiler. Hence it would appear, that from 180 lb. to 200 lb. of coals were burned hourly to maintain a chimney current of 35 ft. per second, or a discharge of air of 70 cubic feet in that time. This result agrees as nearly with that obtained at Sir Henry Meux's brewery as can be expected in experiments of this nature. The coal employed in the latter establishment is of the excellent Welch quality called Llangennech, which burns without smoke. Were other proprietors of great manufactories to imitate this patriotic example, one of the worst nuisances of London would be abated.

The value of fans to sweeten the atmosphere is beginning to be fully appreciated in the factories, more especially in the power-loom apartments, where several hundred persons are congregated together in a moderate space. The beneficial mode of mounting them, with this view, described in the *Philosophy of Manufactures* has been instrumental in drawing the attention of manufacturers to so simple and efficacious a means of promoting the health of their work-people. In these circumstances, it will appear somewhat surprising that none of the members of the late Parliamentary Committee, nor any of the scientific gentlemen whom they examined, should have made the slightest allusion to mechanical ventilation. This omission will appear the more remarkable, since a celebrated member of the Royal Society, Dr. Desaguliers, one hundred years ago, applied a similar invention, as he says, "to the clearing the House of Commons of foul air." The following paragraph of his memoir deserves peculiar notice, as it shows with what a roundabout of futile expedients the public has been deluded for a century past: —

"In the year 1736," says the doctor, "Sir George Beaumont, and several other members of the House of Commons, observing that the design of cooling the House by the fire machines above described (like the pumping stoves of the Marquis de Chabannes in our day) was frustrated, asked me if I could not find some contrivance to draw the hot and foul air out of the House, by means of some person that should entirely depend upon me; which, when I promised to do, a committee was appointed to order me to make such a machine, which, accordingly, I effected, calling the wheel a centrifugal, or blowing-wheel, and the man that turned it a ventilator. This wheel, though in some things like Papin's Hessian bellows, differs much from it, being more effectual and able to suck out the foul air, or throw in fresh, according as the Speaker pleased to command it; whose order the ventilator waits to receive every day of the session, the wheel being still in use."

The wheel is described as being 7 ft. in diameter, 1 ft. broad, as taking in air at its centre, and revolving concentrically with its case. It was worked, at least occasionally, from the year 1736 down to the year 1743, when the first edition of the *Experimental Philosophy* of Desaguliers was published. The machine probably remained in the chamber over the House of Commons, and fell a victim to the fire which lately consumed that time-honoured edifice.

As the ventilating fan of Desaguliers was worked by a man turning a winch, it could not have made more than forty revolutions in a minute, whence the mean speed of the tips of its vanes could not have exceeded 15 ft. in a second. In considering, therefore, the defectiveness of its construction, as well as the small area of its discharge-pipe, it was, probably, not misnamed "a philosophical toy" by Sir Jacob Ackworth, then First

Lord of the Admiralty, who went down to Woolwich to see its performance in ventilating the hold of His Majesty's ship the Kinsale.

It does not appear that, since the time of Desaguliers, the ventilating fan has been subjected to scientific experiment and examination; for M. Pouillet, a distinguished French philosopher, described last year, in the sixth livraison of his *Portefeuille Industriel*, with high but unmerited commendations, a fan erected at Rouen for blowing a foundery cupola, which, on trial, was quite inefficient in propelling the air, while it shook the floor where it stood with tremendous violence. This fan is of the concentric construction, and must, therefore, expend the chief part of the power applied to drive it, in carrying the air round with its vanes, instead of throwing it off at the discharge-pipe. The English Company of Machine-makers settled at Rouen, to whom it belongs, have been obliged to alter it after the plan now commonly adopted in Lancashire.

The following sketches (*figs*. 19. to 22.) and experimental illustrations will, I hope, throw some light upon the operations of a ventilating fan.

Fig. 19. is intended to show, by the course of the lines traced in it, that in the concentric fan only two leaves out of five are effective, and that very little more than one half of the exit pipe is occupied with the regular current of air produced by the rotation of the leaves. The quantity thrown out by virtue of the pressure under which the air is kept by the centrifugal force is, therefore, very small, being intercepted by the current from the leaf *a*, whose tangent crosses the exit pipe completely, and nearly at a right angle.

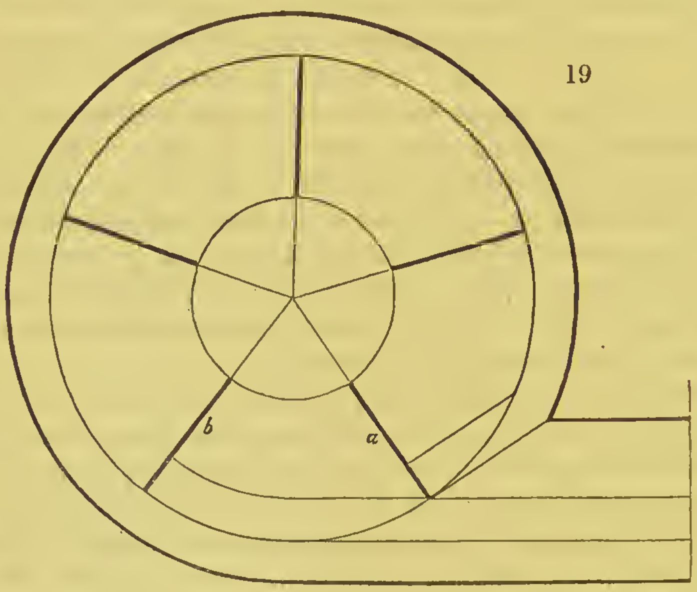
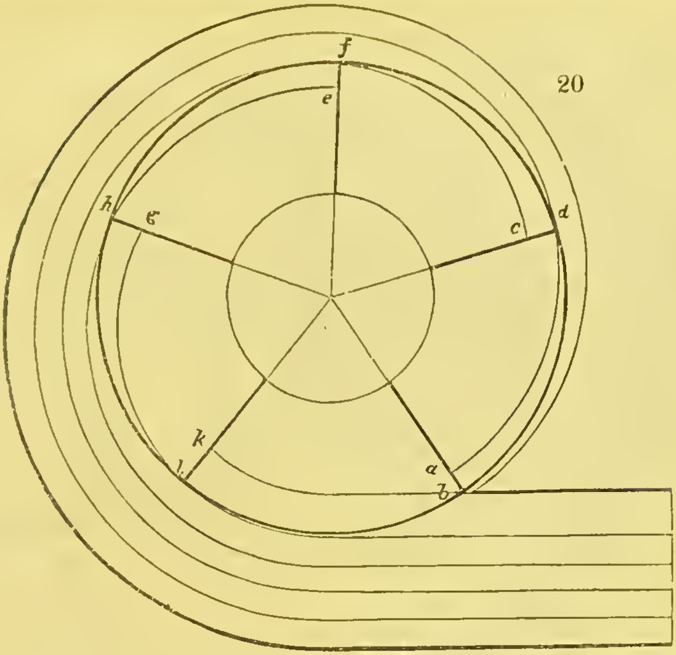


Fig. 20. shows that in the eccentric fan *all* the leaves are effective, and that the exit pipe is entirely filled with a current

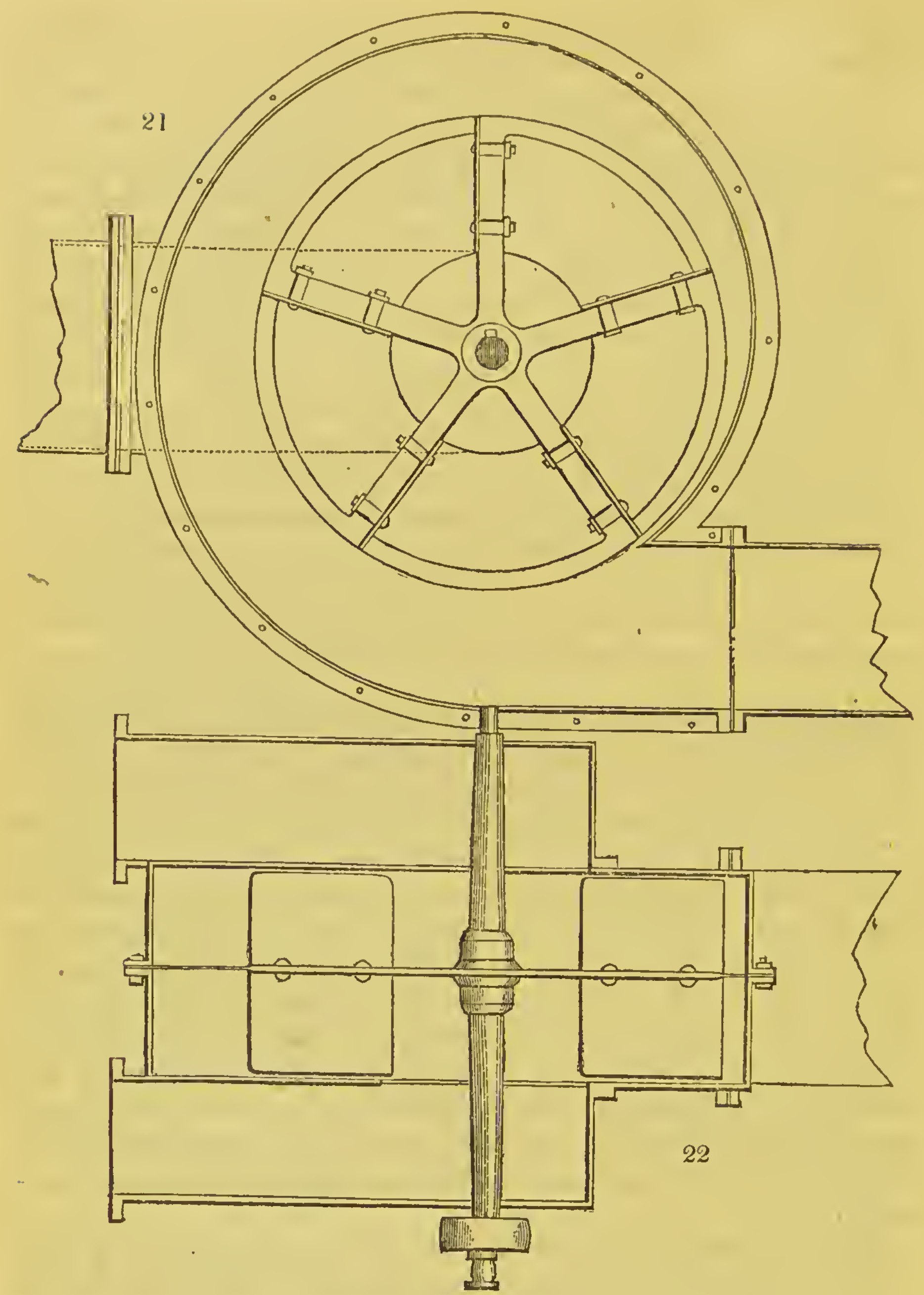


20

from the impulsion of the vanes, independently of any pressure by centrifugal force; except as regards its supply of air from the centre, which obviously depends upon the unbalanced pressure of the atmosphere. That the air cannot enter the exit pipe at less speed than the speed at which the points *a*, *c*, *e*, *g*, *k* revolve, would, at first sight, seem to be certain; for the sum of the lines *a b*, *c d*, *e f*, *g h*, and *k l* is equal to the length of the vertical axis of the exit pipe. And, since the points *a*, *c*, *e*, &c., move at a rate of from $\frac{7}{8}$ to $\frac{8}{9}$ of the extremities of the leaves, the speed will be, at least, $= \frac{7}{8} \times 120 = 105$ ft. per second, when the tips move at 120 ft.; whereas, I found 94 ft. per second to be the velocity by experiment. The difference may be ascribed, as I have already said, to the inertia of the air, the lateral communication, and consequent loss of motion, by the eddies thus produced.

Figs. 21. and 22. represent the section and plan of a fan, which is considered by my ingenious friend Captain Ericsson to be of the best construction. The drawing is so plain as to supersede the necessity of a detailed description.

With regard to the quantity of air thrown out by a fan of this construction, it may be ascertained approximately by multiplying the speed of the points *a*, *c*, *e*, &c., by the sectional area of the exit pipe. The absolute force required to work this fan may be calculated, with sufficient accuracy, in the following way: — Suppose the extremities of the leaves to move at the rate of 80 ft. per second, the sectional area of the exit pipe to be square feet; then $2 \times 80 = 160$ cubic feet; which number, multiplied by 60 seconds, gives a product of 9600 cubic feet of air discharged per



minute. This, reduced into weight, will be $\frac{9600}{13}=738$ lb., put into motion every minute, at the rate of 80 ft. per second. Now, in order to acquire a velocity of 80 ft. per second, a body must be allowed to fall freely through a space of $\frac{80+80}{64}=100$ ft.; hence the force required to give to 738 lb. a velocity of 80 ft. per second will be equal to $738\times100=73{,}800$ lb., lifted 1 ft. high. This number, divided by 33,000, will give a quotient equivalent, in pounds, to the impulsive power of $2\frac{1}{4}$ steam horses for working such a fan.

This calculation agrees well with the result of the trial of a large fan constructed by Captain Ericsson, in the year 1831, at Liverpool, for supporting combustion without a chimney in the furnace of a boiler of 100 horses' power on board the Corsair steam-boat. The diameter of this fan was 4 ft. 6 in.; area of the exit pipe, 3 square feet; effective speed of vanes, 80 ft. per second. To work this fan, he constructed a steam-engine, having a 4-in. cylinder, and 10-in. stroke. The result proved that 120 strokes per minute, with steam of 45 lb. pressure to the square inch, were required to produce a speed of 80 ft. in the fan. The engine being of excellent workmanship, from the well-known factory of Messrs. Fawcett and Preston, at Liverpool, and its motion being directly communicated to the fan, we may fairly conclude that at least 30 lb. to the square inch was the effective pressure of the steam. This number, multiplied by 12, being the area of the piston in square inches, gives a product of 360 lb. for the moving force; and this product, multiplied by 200 ft. (the speed of the piston), is equivalent to 72,000 lb., lifted 1 ft. high per minute, which represents the power of the engine. The quantity of air $= 80 \times 30 = 240$, multiplied by 60 seconds $= 14{,}400$ cubic feet per minute. The temperature of the air, as it entered the fan, was about 300°, and was, therefore, reduced in specific gravity to about 20 cubic feet to a pound. Hence $\frac{14400}{20} = 720$ lb. weight of air thrown out per minute; which, lifted to a height of 100 ft. (the elevation necessary to produce a velocity of 80 ft. per second), would require a force equal to $720 \times 100 = 72{,}000$ lb., lifted 1 ft. high, per minute; which quantity exactly coincides with the power of the steam-engine.

It may be worth while to state, though the fact will be obvious to every practical engineer, that, when the exit pipe of the fan was stopped up, and only a little steam admitted into the steam-engine, the fan-leaves moved at an immense speed, the confined mass of air being kept in perpetual rotation; but, whenever the pipe was again opened, so as to admit the stagnant air, the engine was brought nearly to a stand by the weight and inertia opposed to its motion.

The observations of Saussure, and other scientific travellers in mountainous regions, demonstrate how difficult and painful it is to make muscular exertions in highly rarefied air. Even the slight rarefaction of the atmosphere corresponding to a low state of the barometer at the level of the sea often occasions no little discomfort to persons of delicate frame; while the opposite condition of increased pressure, as indicated by a high barometer, has a bracing effect upon both body and mind. Hence, in ventilating crowded apartments, such as the Houses of Parliament, instead of having recourse to chimney draughts, as has been hitherto the invariable practice, and which operates by pumping out, exhausting, or attenuating the air (a fact elegantly illustrated by Dr. Wollaston's differential barometer), we ought, upon every sound principle of physiology, rather to increase the density and spring of the atmosphere, by throwing in a continual current of pure air, brought to the proper degree of temperature and moisture in a chamber of preparation. The air, in its ingress and egress, being placed under the control of valves regulated by index-dials, might have its density modified to a very considerable extent, and thus become fitted to supply the lungs of the inmates with an elastic element, eminently conducive to their health, comfort, and activity.

In applying a principle of this kind to ventilate such a noble pile of buildings as the new Houses of Parliament will be, two or more fans of suitable size should be erected in a small apartment on the ground-floor, for the sake of solidity, and near the centre of the range, for the facility of distribution. These fans should be driven by a small steam-engine, with a boiler heated with coke, on Messrs. Braithwaite's safety plan, emitting no smoke, nor requiring an elevated chimney to disfigure the edifice. From the fans, proper conduits, made of wood, brick, or sheet iron, should be led to the floors of the several chambers to be ventilated. The terminations of these conduits should be furnished with proper valves, for regulating, by a dial index, connected with a cord or wire (like a common bell-pull), the degree of ventilation required, according to circumstances.

In the state of scientific excellence at which the arts have arrived in this country, especially among the factory engineers, no doubt can exist about the propriety of heating the new Houses of Parliament by means of a series of substantial cast-iron pipes, filled with steam, placed in a sunk area below the level-line of the chambers; from which, as a vast magazine, genial air, of a proper thermometric and hygrometric constitution, could be readily distributed, in any desired quantity, to renovate the atmosphere of every lobby and apartment in the buildings. The same boiler which furnishes steam to the engine would be adequate to furnish a supply to the warming pipes in ordinary weather. In very severe weather, however, an additional steam boiler could be brought into action; the main object being to provide such a body of genial pure air as country gentlemen are accustomed to breathe in a fine summer's day on their breezy lawns, but never to be under the necessity of inhaling the mephitic vapours emitted by the lungs and skin of themselves and their neighbours, as has been hitherto the established practice in both Houses of Parliament at every interesting debate.

The quantity of steam-pipe surface, at a temperature of 212° Fahr., requisite to heat a certain volume of air in the large apartments of a well-built cotton mill, has been ascertained with perfect precision; and may be estimated, in round numbers, at one superficial foot of pipe for 150 cubic feet of space, to insure to the air a steady temperature of 62°, which is the mean summer warmth of the atmosphere in England. It would be prudent to have at command a great magazine of air for the Parliament, since the consumption of fuel under an economical disposition of apparatus would be utterly insignificant, in comparison of the health and comfort of the legislative bodies of the empire.

For the following estimate of the quantity of cast-iron pipe necessary to maintain a healthy and comfortable temperature during winter in the Long Room in the Custom-house, I am indebted to Mr. Fairbairn of Manchester, whose experience and success as a factory engineer are such as to give confidence to his statement. The above apartment is 190 ft. long, 64 ft. wide, and 46 ft. high, containing fully 20,000 cubic yards of space. Two ranges of cast-iron pipes, 8 in. in diameter, properly distributed upon the floor, close to the bottom of the desk-partitions along the two sides and ends of the room, having arched junction pipes of wrought iron 2 in. in diameter, rising round the entrance doors, will be fully adequate to warm it in the coldest winter weather of this climate. A suitable low-pressure self-feeding steam-boiler, with proper pipes and mountings, would, at the usual factory prices, cost no more than *500l.* Upon this plan, less than one half of the quantity of fuel would be required, of what is now consumed by the air-roasting furnaces, in generating malaria, discomfort, and disease.

Among the stove-doctors of the present day, none are more dangerous than those who, on pretence of economy and convenience, recommend to keep a large body of coke burning slowly, with a slow circulation of air. An acquaintance with chemical science would teach them that, in the obscure combustion of coke or charcoal, much carbonic oxide is generated, and much fuel consumed, with the production of little heat; and physical science would teach them that, when the chimney draught is languid, the burned air is apt to regurgitate through every seam or crevice, with the imminent risk of causing asphyxia or death to the inmates of apartments so preposterously heated. To obtain the maximum quantity of heat from fuel, its combustion ought to be very vivid, and the caloric thus evolved diffused over the largest possible surface of conducting materials. This principle has been judiciously applied in several French factories. Great care must be taken not to suffer the surfaces to be heated above 240° Fahr. It has been proved that workpeople employed in calico-drying rooms heated by such means become emaciated, wan, and sickly, while they remain perfectly healthy, and even blooming, in rooms of which the air is more highly heated with steam-pipes.

Among the many causes assigned by pathologists for the infirm health of persons who confine themselves much to warm apartments, and seldom venture into the open air, one of the most operative has been altogether overlooked — the rarefaction, by diminished pressure and heat, of the atmosphere which they breathe.* I find, if a differential barometer, containing proof spirit in the one leg, and oil in the other, have its horizontal tube thrust into the key-hole of a snug winter parlour, that, on turning the stopcock attached to it, the junction line of the two liquids will rise from half an inch to an inch, according to the tightness of the room, and the force of the fire. By opening the street door a further rise will take place. The pulmonary and sanguiferous systems being, in such circumstances, deprived of their due proportion of chemical aliment and physical support, must languish, and spread exhaustion over the nervous, muscular, and digestive functions. I am persuaded that many of the valetudinarian ailments of the opulent inhabitants of the United Kingdom may be traced to their breathing an air unduly rarefied by chimney draughts. Every well-constructed mansion should have its underground storehouse of temperature, from which a constant supply of genial air could be poured into the several apartments in such quantities as are wanted for comfort, with the effect of increasing rather than diminishing its density. Open fires would, in this case, be used only for enlivening the scene; and, being supplied with abundance of air from the ventilating orifices, could create no appreciable rarefaction.

---

* Since the first portion of this paper was put to press, my attention has been called to a memoir of M. Junot, lately published in Paris, concerning the effects of compressed and rarefied air upon the human body. When a person is plunged in condensed air, he breathes with "a new facility;" he feels as if the capacity of his lungs were enlarged; his respirations become ample, and less frequent; at the end of fifteen minutes, he experiences an agreeable warmth in his chest, as if the pulmonary cellules, long strangers to the contact of air, were dilated anew to receive the genial spirit; while the whole animal economy sucks in at each inspiration a fresh supply of life and vigour.

The arterial system acts with increased force, while the veins on the surface of the body are depleted, and may be made even to disappear. The functions of the brain are excited, the imagination becomes lively, and the thoughts are "accompanied with a peculiar charm." The movements of the muscular system are rendered, at the same time, freer and more energetic. Digestion becomes more active, but without thirst (*la soif est nulle*); because the secretory system participates in the increased vigour of the arterial.

In rarefied air, the effects are nearly the reverse of the above: the breathing is constrained, feeble, frequent, ending in dyspnœa, or an asthmatic paroxysm; the pulse is quick, and easily compressed; hæmorrhages often occur, with a tendency to fainting; at length, a defect of vital energy, or apathy, supervenes. The kidneys and salivary glands cease to secrete their respective fluids. M. Junot proceeds to describe the effects of compressed and rarefied air upon different parts of the human body, both in a state of health, and in the cure of diseases, by means of a very ingenious mechanical invention; for an account of which however, I must refer to the memoir itself, in the *Archives Générales de Médecine*, seconde série, tom. ix. p. 157.